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POPULATION EXPOSURE TO IONISING RADIATION: DOSE MAGNITUDE AND BASIC RADIATION PROTECTION PRINCIPLES

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ABSTRACT

The paper presents major sources of population exposure to ionizing radiation and the magnitude and distribution among various sources. Natural radiation sources are part of human environment. Due to external exposure from space radiation, external exposure from terrestrial radiation, internal exposure from inhalation of radon and thoron and their progeny and due to internal exposure from radionuclides in the body, as a global average, the natural background radiation is 2.4 mSv per year. Apart from natural radiation, nuclear and isotopic techniques represent a wide range of human activities, and for more than a century have very important applications in various areas of life. A brief overview of these methods used in agriculture, industry, science and research, archaeology, history and medicine and their radiation impact will be provided. Parallel to expansion of radiation application, the concerns related to health effects of ionizing radiation have been raised. The scientific discipline called radiation protection has an aim to protect people and environment form excessive and unnecessary exposure to ionizing radiation. There are three basic principles in radiation protection: justification, optimisation of protection and individual dose limitations, and overview of these will be given in the paper.

Key words: *radioactivity, radiation dose, radiation source, population, environment*.

INTRODUCTION

Radioactivity and radiation is a part of our natural environment, which existed on Earth before any sign of life. Later, humans learned how to use radiation and it has become an important part of our life (Bethge et al., 2004; Bushberg et al., 2003; Eyre, 1996; UNSCEAR, 2010). Nuclear and isotopic techniques present a wide range of human activities. For more than a century, they have been applied in different areas, as nuclear energy, agriculture and biotechnology, in the management of water and marine resources, industry, science and research, archaeology, history and medicine (Magill and Galy, 2005). Different nuclear technologies bring on daily basis immense benefits in diagnosis and treatment of disease, in control of industrial processes, for development of science and power generation. In general, application of radiation and nuclear methods are based on various properties of nuclei and radiation, such as the interaction of radiation with matter, radiation detection, biological effects of radiation and static and dynamic nuclear properties (magnetic properties, stability, radioactive decay) (Bethge et al., 2004).

In parallel with the expansion of application of radioisotopes and nuclear methods, awareness about of the harmful effects of ionizing radiation has increased (IAEA, 2004) . The new findings resulted in the development of new scientific and professional discipline that is now known today as the Radiation Protection. This discipline pervades all applications of radiation sources and nuclear methods with an aim to protect people and the environment from unnecessary and excessive exposure to ionizing radiation, seeking to maximize the benefit and minimize the risk in any practice that is associated with radiation (ICRP, 2007).

Although the terms "radiation", "radioactive" or "nuclear" cause of fear and concern, the fact that radiation is a part of our natural environment and has outstanding role in medicine, industry and technology, often is not well understood. The paper presents major sources of population exposure to ionizing radiation, the magnitude and distribution among the various sources of radiation exposure. Different categories of radiation exposure sources are presented: natural radiation sources, medical procedures, consumer products or activities involving radiation sources, industrial radiation sources and exposure of workers due to their occupation.

RADIATION PROTECTION STANDARDS

Dose quantities

Human body does not possess receptor for ionizing radiation and thus, we cannot detect the presence of radiation by our senses. We use other means and specific instrument to detect and measure presence of radiation as gas, solid-state, chemical detectors and other detectors (Cherry et al., 2003; Martin, 2006). We interpret measurements in a way to express the amount of energy deposited in human body or any part of it, or, alternatively, we can calculate the dose absorbed by a organ followed by radionuclide deposition (internal dosimetry).

The amount of energy deposited per unit mass is called absorbed dose. It is expressed in units gray (Gy=J/kg). Types of ionizing radiation (alfa, beta, gamma, neutrons…) differ in a way they interact with biological material. When different biological effectives of different radiation types is taken into account a new quantity is introduces, called equivalent dose. This quantity includes radiation weighting factors assigned to different radiation types, ranging from 1 for gamma radiation to 20 for alpha particles. It is expresses in units sievert (Sv=J/kg) and provides an index of likelihood of harm for particular tissue or organ. The risk varies from organ to organ and to assess the overall detriment to human body by multiplying organ dose by a tissue weighting factor related to risk for a particular organ. The sum of weighted equivalent doses is called effective dose (ICRP, 2007):

$$E = \sum_T w_T \cdot H_T \tag{1}$$

where w_T presents tissue weighting factor (Table 1) and H_T corresponding equivalent dose for tissue T.

Table 1: Tissue weigting factors, w_T (ICRP, 2007)

Tissue/organ	w_T
Bone-marrow (red), Colon, Lung, Stomach, Breast, Remainder tissues*	0.12
Gonads	0.08
Bladder, Oesophagus, Liver, Thyroid	0.04
Bone surface, Brain, Salivary glands, Skin	0.01

* Remainder tissues: Adrenals, Extrathoracic (ET) region, Gall bladder, Heart, Kidneys, Lymphatic nodes, Muscle, Oral mucosa, Pancreas, Prostate (male), Small intestine, Spleen, Thymus, Uterus/cervix (female).

The effective dose allows to represent exposure by a single number and to compare different exposures types. It takes into account type and energy of radiation and tissue radiosensitivity, it applies to both external and internal exposure and thus, gives a broad indication of the health detriment. As a measure of dose to group of people and whole population, collective effective dose is used. It is a sum of effective doses for all exposed people with units man Sv (IAEA, 2004; ICRP, 2007).

Radiation sources in global prospective

Ionizing radiation enters our lives in a variety of ways. It is merely fact of our life, which arises both from nature and artificial processes (UNSCEAR, 2010). According to their origin, we classify radiation sources to natural and artificial or man-made. Each source has two important properties: the dose that it delivers and possibility of humans to affect this dose. Until recently, natural radiation was pure background phenomena, however it is well know that in some cases exposures to natural radiation can be remarkably high. In the case of radon exposure, there possible actions that can lead to dose reduction, however, exposure to other natural sources almost cannot be altered. Since more than a century ago, use of radiation and radioactivity has become important element of human activates which include energy production, medicine, fire detection, light prevention, agriculture, geology, industry and many others. All these activities in spite to huge benefit increase exposure to ionizing radiation, which varies immensely between different applications. Variations in radiation exposure are much larger due to man-made sources of radiation compared to natural sources. Exposure man-made sources is by far more controllable, and extend of this process is based on balance of benefits and associated risks.

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) regularly publishes data on doses from all sources. According to UNSCEAR report form 2010, annual dose, averaged over the population worldwide is about 3.0 mSv in total. About 2.4 mSv of this is from natural sources and 0.6 mSv from man-made sources (Table 2).

Table 2: Annual average doses and ranges of individual doses of ionizing radiation
(UNSCEAR, 2010)

Source	Annual average dose (mSv)	Typical range of individual doses (mSv)
Natural		
Radon	1.26	0.2-10
External terrestrial	0.48	0.3-1
Ingestion	0.29	0.2-1
Cosmic	0.39	0.3-1
Total natural	2.4	1-13
Man-made		
Medical diagnostics	0.6	0-80
Atmospheric nuclear tests	0.005	-
Occupational	0.005	0-20
Chernobyl	0.002	-
Nuclear fuel cycle	0.0002	-
Total man-made	0.6	-

Radiation effects

Ionizing radiation has enough energy to cause damage in cells which can further increase the risk of cancer later in life. However, the health effects of ionizing radiation are dependent on the dose received. Health effects of ionizing radiation are classified into two types: those that are visible, documented and confirmed within a relatively short time - weeks to a year or so (called tissue reactions or formerly deterministic effects: skin erythema, hair loss, cataract, infertility, circulatory disease) and others which are only estimated and may take years or decades to manifest (called stochastic effects: cancer and genetic effects). Tissue reactions have thresholds, which are typically quite high (order of magnitude of couple of Gy) which is mainly related to accidental situation (ICRP, 2007; IAEA, 2004). Stochastic effects include cancer and genetic effects, but the scientific evidence for cancer in humans is stronger than for genetic effects. According to ICRP Publication 103 (2007), detriment-adjusted nominal risk coefficient for stochastic effects for whole population after exposure to radiation at low dose rate is 5.5% per Sv for cancer and 0.2% per Sv for genetic effects. This gives a factor of about 27 more likelihood of carcinogenic effects than genetic effects. There has not been a single case of radiation induced genetic effects documented in humans so far, even in survivors of Hiroshima and Nagasaki.

Basic radiation protection principles

Radiation protection standards are way to control exposure to ionizing radiation. The standards in this area are consistent trough the world, mainly due to internationally recognized framework. The standards are based on the conservative assumption that the risk is directly proportional to the dose, even at the lowest levels, though there is no evidence of risk at low levels, i.e. "linear no-threshold (LNT) hypothesis", which is recommended for radiation protection purposes only such as setting allowable levels of radiation exposure of individuals (ICRP, 2007).

In any country, radiation protection standards are set by government authorities, generally in line with recommendations by the International Commission on Radiological Protection (ICRP), International Atomic Energy Agency (IAEA) and coupled with the requirements of basic radiation protection principles. The three key points of the ICRP's recommendations are (ICRP, 2007):

1. Justification, according to which no practice should be adopted unless its introduction produces a positive net benefit;
2. Optimization, according to which all exposures should be kept as low as reasonably achievable, economic and social factors being taken into account;
3. Dose limitation, stating that exposure of individuals should not exceed the limits recommended for the appropriate circumstances.

National radiation protection standards are based on ICRP recommendations. They set dose limits for both occupational and public exposure categories, whereas this does not apply to medical exposures. The ICRP recommends that the maximum permissible dose for occupational exposure should be 20 mSv per year averaged over five years (i.e. 100 mSv in 5 years, about 8 time average dose from natural background) with a maximum of 50 mSv in any one year. For public exposure, 1mSv per year averaged over five years is the dose limit (ICRP, 2007). In both categories, the figures are over and above background levels, and exclude medical exposure.

Practices are activities that involve deliberate use of ionizing radiation. They are clearly defined and regulated. On the other hand, we do not take measures to reduce exposure from natural radiation, although there are some interventions in the case of high exposures in homes and at work.

The first requirement of the system of radiological protection for practices is the need to consider harmful costs in the light of benefits. In most cases, radiation effects are just one of the possible harmful outcomes, taking into account social and economical effects. This applies to all practice, including medical applications of ionizing radiation where each procedure has to be judged on its own merits, both for patients and population as a whole. As we assume that no dose is free from risk, it is important to reduce all doses as low as reasonably achievable (ALARA). Constrains are imposed to optimize exposure, usually as a fraction of annual dose limit related to particular practice or industry. For member of the public, in the phase of planning of new practice pr source, typical dose constraint is 0.3 mSv. Application of dose constraint and diagnostic reference levels (DRL) in the case of medical exposures have provided practical means for reducing doses globally (IAEA, 2004; ICRP, 2007).

NATURAL RADIATION SURCES AND EXPOSURE PATTERNS`

Natural radioactivity is a source of continuous exposure to human beings. It is present in the human environment due to the presence of cosmogenic and primordial radionuclides in the Earth's crust.

Natural environmental radioactivity and the associated external exposure due to gamma radiation depend primarily on the geological and geographical conditions, and appear at different levels in the soil of each region in the world. There are three naturally occurring decay series, headed by the radionuclides ^{238}U, ^{235}U, and ^{232}Th. These series are commonly called the uranium series, the actinium series, and the thorium series respectively. The three famillies of radioactive heavy elementsaccount for much of the background radiation to which humans are exposed. Also the primordial radionuclide ^{40}K, which is evrywhere present, produce significant human exposure.

Exposure to natural radiation represents the most significant part of the total exposure to radiation in the environment. Worldwide average annual effective dose from natural sources is 2.4 mSv (UNSCEAR, 2010). Almost the one fifth of total dose (0.48 mSv) belongs to external exposure from terrestrial radiation and 0.39 mSv to exposure from cosmic rays (Table 2).

A significant contribution to natural exposure of humans is due to radon gas, which emanates from the soil. Radon (^{222}Rn) is a natural radioactive gas produced upon uranium (^{238}U) decay. Its physical properties are: colorless and odorless gas. In the living environment, the gas is found diluted in low concentrations (5-10 Bq/m^3). In the indoor spaces, such as apartments, radon may be accumulated. The indoor radon concentration depends on building construction, construction site characteristics and meteorological conditions, as well as on the construction materials. It is believed that exposure to certain levels of radon concentrations increase the risk of lung cancer. The risk depends on its concentration in the apartment and time spent in the area. Public exposure to radon and its radioactive daughters, present in the environment, results in largest contribution to the average effective dose received by human beings. Worldwide average annual effective dose from radon is 1.26 mSv (Table 2, UNSCEAR, 2010). The results of the radon concentration measurement in Belgrade showed that in the most of the apartments radon concentration is below 200 Bq/m^3 (Eremić-Savković et al, 2002; Popović et al, 1996).

Human activities involving the use of radiation and radioactive substances cause radiation exposure in addition to the natural exposure. Some of those activities simply enhance the exposure from natural radiation sources. Examples are the mining and use of ores containing naturally radioactive substances and the production of energy by burning coal that contains such substances (Pantelic et al, 2002).

ENVIRONMENTAL POLUTION

The global source of artificial radionuclide contamination in our country are fallout due to nuclear testing throughout the 20^{th} century and deposition of radionuclides from the regions of nuclear accidents.

Partial meltdown of the reactor at Chernobyl in April 1986 released high amounts of radionuclides into the environment. As a result of the accident, the reactor was destroyed and about $14 \cdot 10^{18}$ Bq was ejected in the environment during 10 days. ^{131}I, ^{134}Cs and ^{137}Cs were the most important and the most dangerous radionuclides released and spread over a large part of Europe (IAEA, 2006). The deposition of radiocesium from the Chernobyl accident in Serbia occurred at the beginning of May 1986. The ^{137}Cs was deposited on the ground, forage crops, grass and feed plants of ruminants. During the following years, ^{137}Cs entered all compartments of the affected ecosystems. The main pathways of radionuclides in the human body are inhalation and ingestion through food and drinking water. ^{137}Cs activity was monitored in the environment after the Chernobyl accident. ^{137}Cs is one of the radionuclides of public health importance because of its long half-life (30 years) and its nearly complete gastrointestinal absorption in humans. When ingested from contaminated food, the absorbed caesium accumulates into all tissues. The effective dose from ^{137}Cs due to food ingestion in 1986 was 0.66 mSv and decreased in subsequent years. (Maksic et al, 1997).

The Fukushima Daiici nuclear power plant accident caused a large regional release of radionuclides into the atmosphere and subsequent radioactive contamination of the environment. Once released into the atmosphere, a long-range atmospheric transport processes can cause widespread distribution of radioactive matter. The fallout consisting of short-lived and long-lived radionuclides, eventually affects humans either directly or indirectly by entering the food chain through plants and animals. The occurred radioactive contamination originating from Fukushima was detected not only in Japan and Asia, but also in the entire northern hemisphere, including USA and Europe.

Gamma spectrometry measurement of aerosol samples in Belgrade showed clear evidence of fission products ^{131}I, ^{134}Cs and ^{137}Cs within two weeks after the accident (Nikolić et al, 2012). The activity diminished with time due to dispersion in air and, in case of ^{131}I, short half life.

MAN-MADE RADIATION SOURCES AND EXPOSURE PATTERNS

Industrial application of ionizing radiation

Application of radiation sources is of paramount importance in the industry, primarily in the field of processes control as well as in the radioactive gauges, for measuring the level, density and thickness of various products. Radiation sources are used for detection of defects in materials, for the corrosion detection and control and error detection in welds. Radiographies similar to industrial are nowadays of immense importance in the field of security and prevention of illegal traffic of goods (Magill and Galy, 2005). The properties of material can be successfully determined by detecting changes in the intensity of radiation emitted by the source. This principle is used different radioactive (nuclear) gauges. In general, these devices consist of a radiation source and detector, which is usually a gas (Geiger-Miller counter) or scintillation (usually a crystal) detector. When industrial process requires determination of level of liquid in the container or in the pool, the device consists of a radiation source and detector positioned opposite the source at the level of liquid. In this situation, the change of liquid level results in a change of the signal on the detector. This method has been used successfully to control the content of cans of soft drinks and in the industrial production of thin films, such as plastic or metal foils, floor coverings or paper (IAEA, 2004; Magill and Galy, 2005).

Neutron beams from nuclear reactors and spallation sources are successfully used in radiography of objects consisting of parts with different cross sections for neutrons. Given that materials such water and hydrocarbons efficiently scatter thermal neutrons (which is not the case with the gaseous mediums and metal), neutron radiography is an ideal technique for analysis of density variations in materials that absorb and scatter neutrons. In contrast to the x-radiation interactions, neutrons interactions do not depend systematically on atomic number of media, although some lighter atoms (boron and hydrogen) have a significant cross section for interaction (Magill and Galy, 2005;Martin, 2006).

Application of radioactive tracers is old as the knowledge of radioactivity. Presence of radioactive traces enables detection of radiation and non-invasive analysis of physical and chemical properties of materials to which these tracers have been added in very small quantities. For example, the labeling of pesticides and insecticides by ^{14}C isotope of carbon, it is possible to monitor the degradation products in the biosphere. In other areas, such as biochemistry, hydrogen isotope tritium ^{3}H or ^{32}P isotope of phosphorus is being successfully used. This enabled successful monitoring phosphorus absorption in plants (IAEA, 2004; IAEA, 2011).

Based on biological effects of ionizing radiation, various nuclear methods have found a significant place in the sterilization of food and insect control. Also, the results of the analysis of radiation effects in different materials enabled the use of radiation for modification of material properties. Effects of ionizing radiation are successfully used to destroy pest populations by male insect sterilization, for improving sanitary conditions for both humans and animals and to prevent the spread of infectious disease (IAEA, 2011). In radiation sterilization of food, by exposing samples to doses on the order of kGy, the taste is preserved, which is great advantage of this method in comparison to some alternative methods such as pasteurization (Martin, 2006; IAEA, 2011).

Industrial radiography is a discipline in which the sources of ionizing radiation are used for testing and analyzing the internal structure of materials and objects. These methods are entirely non-destructive and are based on the application of x- or gamma radiation. In addition to industrial applications, x-radiography and gamma radiation and is widely used for baggage and cargo control in air and other modes of transport.

Medical application of ionizing radiation

Nuclear technologies are the basis of modern medicine today. Medical procedures and techniques based on the application of radiation, radioisotopes and nuclear methods take a central place in modern health systems. These methods are an example of transfer of high technology and modern scientific knowledge in daily medical practice, whether in terms of diagnosis or treatment of disease.

First applications of radiation sources linked specifically to medicine are almost as old as the human knowledge of radioactivity and x-radiation. In addition to the long history of medical use of radiation cause the least controversy in public, primarily because of clear awareness among the population about the benefits arising from use of radiation sources for diagnosis and treatment of disease. For more than a century, medical imaging is used for the study of anatomical, morphological, biochemical and physiological properties of the human body. These methods allow the presentation of complementary structures (anatomy), composition (biology and chemistry) and function (physiology and metabolism) of the human body. Depending on the methods and techniques you use to generate images of internal body structures, imaging methods can be classified broadly in the imaging by x-radiation, (nuclear) magnetic resonance imaging and radioisotope (PET, SPECT) imaging and hybrid imaging based on fusion of images obtained by different methods (Ciraj.Bjelac et al., 2012).

Application of x-radiation in medical imaging has a mass application in the world and a clear trend of growth over the past few decades (Ciraj-Bjelac et al, 2011, UNSECAR, 2010). These techniques include conventional radiography and fluoroscopy, computed tomography (CT), mammography and interventional procedures in radiology and cardiology. Despite the great diversity and different technological levels, all these methods are based on a selective absorption of x-radiation in anatomical region that is a subject of investigation (Bushberg et al, 2002).

Radioisotope imaging is the subject of diagnostic nuclear medicine. Images resulting from the emission of radiation from radiopharmaceuticals are reflecting the spatial and time distribution of radionuclides. If based on emission of photons, the technique called SPECT (Single Photon Emission Tomography), while emission of photons from positron annihilation is called PET (Positron Emission Tomography). Nuclear diagnostic imaging methods provide valuable information on physiological and biochemical processes and are complementary to other imaging methods such as conventional radiology, MRI and ultrasound (Hendee et al, 2002; Iniewski, 2009). These methods are very important in the diagnosis of diseases of the heart, brain, lung, and kidney or in the diagnosis of malignant disease and their follow up. One of the most common applications of nuclear methods in medicine is its basis has use of gamma camera (NaJ scintillator) which detects the radiation emitted by the radiopharmaceutical selectively bound to the region of interest (Christioan et al, 2007). More than 20 000 gamma cameras are in use worldwide. They are used to perform more than 33 million examinations annually (UNSEAR, 2010).

Hybrid imaging methods, e.g. PET is now available in more than 1000 hospitals in the world (UNSECAR, 2010). Modern PET systems are integrated with units for computed tomography, forming a hybrid imaging system PET/CT. By annihilation of positrons from the accumulated radiopharmaceutical and electrons from the surrounding tissue, two photons of energy 0511 MeV are emitted. Using coincident technique, it is possible to determine a place of their origin in the organ. Used radionuclides belong to the chemical elements that are embedded in complex organic compounds of the body, so this technique is suitable for testing *in vivo* metabolism (Christioan et al, 2007) .

One of the most important applications of radionuclides in radiotherapy is based on the use of sealed radiation sources for external beam therapy, the use of implants for the treatment of prostate cancer, intravascular radiotherapy and use of radiopharmaceuticals in for therapeutic purposes. In addition to these methods, rapid development and implementation of a range of new and effective techniques, such as radioimmunotherapy and ion beams is expected in near future (Johns and Cunningham, 1983; Hohloch et al., 2011, Mayles et al., 2007, Nakaya et al, 2010). External beam radiotherapy, dose of ionizing radiation is produced by radiation sources outside the body, using photons or electrons of energies of several MeV, which is sufficient for the penetration of radiation to tumour sites in the body. A source of radiation in radiotherapy (radionuclide) is mainly ^{60}Co or linear accelerators. Recently, devices containing a large number of sources of ^{60}Co, known as "Gamma Knife", which allows for very sophisticated and highly-localized brain therapy have been developed (Mayles et al., 2007, Nakaya et al, 2010). Hundreds of thousands of patients each year is referred to brachytherpy treatment (in the Greek language *brachys* means close). In this technique, an sealed source of radiation is introduced into the body cavity or tissue and its proximity to the tumors, provides the necessary dose for tumor and minimal dose to surrounding healthy tissue (Mayles et al., 2007).

Radiation exposure for medical use of ionizing radiation

Diagnostic and interventional procedures involving x-rays are the most significant contributor to total population dose form man made sources of ionizing radiation with ever increasing use (UNSECAR, 2010). X-ray imaging generally covers a diverse range of examination types, many of which are increasing in frequency and technical complexity. Trends in radiation exposure from diagnostic radiology are presented in Table 3. Due to increasing importance of radiation burden for medical x-ray examination, clinical dosimetry is becoming an active research and practical area. Objectives of clinical dose measurements in diagnostic and interventional radiology are multiple, as assessment of equipment performance, optimization of practice trough establishment of diagnostic reference levels (DRL) or assessment of risk emerging from use of ionizing radiation.

Table 3: Trends in radiation exposure from diagnostic radiology, adopted from (UNSCEAR, 2010)

Year	Number of examination (million)	Annual per caput dose (mSv)	Collective dose (man Sv)
1988	1380	0.35	1 800 000
1993	1600	0.3	1 600 000
2000	1910	0.4	2 300 000
2008	3100	0.6	4 000 000

Various dosimetric quantities are needed to assess radiation exposures to humans in a quantitative way, in order to assess dose–response relationships for health effects of ionizing radiation which provide the basis for setting protection standards as well as for quantification of exposure levels. As an example, typical effective doses for diverse x-ray examinations in Serbia are presented in Table 4. Nevertheless, radiation burden from medical exposure depends immensely on health care levels, as presented in Table 5.

Table 4: Typical effective doses from x-ray examinations in Serbia

X-ray examination	Effective dose (mSv)	Equivelent number of chest radiographies	Equivelnt number of days of exposure to natural sources
Chest PA	0.05	1	5
Pelvis	0.6	12	60
Lumabr spine	0.8	16	80
Urinary trackt	0.4	8	40
Barium enema	4.8	96	480
CT chest	2.1	42	210
CT abdomen	8	160	800
Coronarography	10	200	1000

An estimated annual number of nuclear medicine examinations worldwide is approximately 33 million, with collective dose of 202 000 man Sv, which represents 35% increase in the last decade. Typical effective doses from nuclear medicine examinations range from 1 mSv for examinations of kidneys, thyroid or lung to 7 mSv for brain scintigraphy (UNSCEAR, 2010).

Table 5: Annual collective dose due to medical exposures, adopted from (UNSCEAR, 2010)

Health care level	Population (million)	Collective dose (man Sv)		
		Diagnostic x-rays	Nuclear medicine	Total
I	1540	2 900 000	186 000	3 100 000
II	3153	1 000 000	16 000	1 000 000
III	1009	33 000	82	33 000
IV	744	24 000	-	24 000
World	6446	4 000 000	202 000	4 200 000

In Serbia, the total annual number of nuclear medicine procedures is approximately 35000, with associated collective dose of 125 man Sv. Average effective per caput was estimated to 17 μSv. Total number of x-ray procedures is approximately 5 million, with associated collective dose of 4500 man Sv and average effective per caput of 0.6 mSv.

Occupational exposure to ionizing radiation

Occupational exposure occurs in many professions. In many areas of industry and medicine, workers are exposed to man-made sources of radiation, whereas some workers, as aircrews or mines can also be exposed to natural sources due to their occupation. All occupational exposures are monitored for external radiation, usually by passive dosimeters, and sometimes also by active personal monitors. Special doses assessment methods are developed for internal exposures (UNSCEAR, 2010). Average annual occupational effective doses are presented in Figure 1.

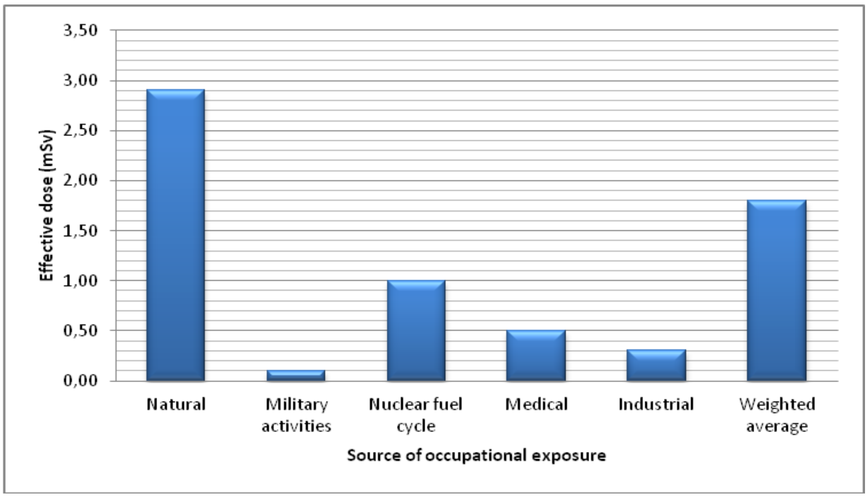

Figure 1. Typical annual effective dose from occupational exposure

Exposure of the general public

Different sources contribute to population exposures. Radionuclides of artificial origin are discharged to the environment from nuclear power industry, military establishments, research organization, hospitals or general industry. These discharges must be controlled and authorized.

Nuclear power industry discharges at each stage of fuel cycle, when variety of gaseous, liquid or solid forms are released to the environment. Estimated radiation burden from these activities is 0.9 man Sv per GW. For approximate power generation of 250 GW annually, estimated collective dose is 200 man Sv and per caput annual dose is approximately 1 μSv. Maximum effective dose from the discharge of artificial radionuclides is about 0.014 mSv in a years, with corresponding collective dose of 5000 man Sv. Although radioactive discharges are well controlled nowadays, this was not the case in the past. Around 500 atmospheric explosions were conducted until 1980. The concentration of radionuclides in air, rain and human diet are at present much lower than in 1960-ties, when they reached the maximum.

The most important radionuclides contributing to human exposure are carbon-14, strontioum-90 and cesium-137, and total dose from external and internal exposure is estimated to be 0.005 mSv annually. The estimated collective dose is approximately 30 000 man Sv (UNSCEAR, 2010; IAEA, 2004).

CONSLUSIONS

Radiation and radioactivity is a part of our nature, it exited in "big bang" and it has been present in universe. Radioactive material are part of Earth, and even human body. However, only a century ago mankind discovered this universal phenomena and it has become an important element of human development that contributes immensely to technological development and quality of our life. Due to external and internal exposures, as a global average, the natural background radiation dose is 2.4 mSv per year. Apart from natural radiation, nuclear and isotopic techniques represent a wide range of human activities, and for more than a century have very important applications in various areas of life, with contribution of 0.6 mSv annually, mainly due to medical exposures. Internationally harmonized standards in radiation protection are developed to control exposure to ionizing radiation. There are three basic principles in radiation protection: justification, optimization of protection and individual dose limitations, all with aim to protect people and the environment from unnecessary and excessive exposure to ionizing radiation, seeking to maximize the benefit and minimize the risk in any practice that is associated with radiation.

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